

1
2 *RAFFLES BULLETIN OF ZOOLOGY XX: XX–XX*

3 Date of Publication:

4 <http://zoobank.org/>

5
6 Category – Conservation & Ecology

7
8 Header – *Mydaus javanensis* activity pattern

9 **The first recorded activity pattern for the Sunda stink-badger *Mydaus javanensis* (Mammalia:**
10 **Carnivora: Mephitidae) using camera traps**

11

12

13 Authors: Stephen H. Vickers^{1*}, Meaghan N. Evans^{1,2}, Mohd Soffian Abu Bakar³ and Benoit
14 Goossens^{1,2,3,4}

15 ¹Organisms and Environment Division, Cardiff School of Biosciences, Cardiff University, Sir
16 Martin Evans Building, Museum Avenue, Cardiff, CF10 3AX, UK; Email:
17 sjedwards94@hotmail.co.uk (*corresponding author).

18 ²Danau Girang Field Centre, c/o Sabah Wildlife Department, Wisma Muis, Block B, 5th Floor,
19 88100 Kota Kinabalu, Sabah, Malaysia.

20 ³Sabah Wildlife Department, Wisma Muis, Block B, 5th Floor, 88100 Kota Kinabalu, Sabah,
21 Malaysia.

22 ⁴Sustainable Places Research Institute, Cardiff University, 33 Park Place, Cardiff CF10 3BA, UK.

23

24

25

26 **Abstract** The Sunda stink-badger *Mydaus javanensis* is a small carnivore inhabiting the Southeast
27 Asian islands of Borneo, Java, Sumatra, and the Natuna Archipelago. Documented sightings are
28 relatively common, yet the species' behavioural ecology remains poorly understood. Whilst the
29 species is reported to be broadly nocturnal, its detailed activity pattern has never been quantified.
30 This study analysed photographic events from a large scale, long-term camera trapping study to
31 assess times of activity for the Sunda stink-badger. The study took place within the lowland riparian
32 forest corridor of the Lower Kinabatangan Wildlife Sanctuary (LKWS) in the Northeast Bornean
33 state of Sabah. Through 2010–2015, 24,506 potential trap nights collected 2,268 Sunda stink-badger
34 images across 470 unique events. Sunda stink-badger activity pattern was modelled using kernel
35 density estimation, and indicated a highly nocturnal activity pattern with no detected activity during
36 the diurnal hours, consistent with previous records. All photographs were taken between 1839 h and
37 0627 h, and modelling indicated two clear peaks in nocturnal activity, the first at 2100 h and the
38 second at 0500 h. Overlap in activity patterns was found to be high ($\geq 80\%$) between wet and dry
39 seasons, and also between moon phases, indicating a lack of seasonal or lunar effects on Sunda
40 stink-badger activity. An encounter rate of 1.92 unique Sunda stink-badger events per 100 potential
41 trap nights was recorded for the LKWS. This encounter rate was lower than those found in other
42 regional studies with lower levels of anthropogenic disturbance, suggesting extensive
43 anthropogenic disturbance may pose a potential negative impact to the species. Whilst activity
44 patterns derived from camera trapping are restricted to movement through the environment, these
45 results have established a baseline for Sunda stink-badger activity patterns within a fragmented
46 habitat subjected to high levels of anthropogenic disturbance, and have improved the basic
47 ecological understanding of the species.

48 **Key words.** camera trapping, Borneo, carnivore, animal behaviour, overlap

49

50

INTRODUCTION

51 The Bornean carnivore guild is a highly biodiverse and highly threatened guild of 25 species
52 (Shepherd et al., 2011); despite increasing research efforts in the region, the behavioural ecology of
53 these species remains poorly understood. Many of the Bornean carnivores reside in remote habitats
54 or at low densities; however, it is their tendencies to display secretive behaviours and nocturnal
55 activity patterns that present the most significant challenges to behavioural studies (Sunarto et al.,
56 2013). Until recently, studies that did occur required long term, large scale, highly expensive or
57 logistically demanding methodologies. To address these issues, camera traps are now being widely
58 utilised to study the guild and have been effective tools to counter some of the difficulties
59 associated with researching tropical carnivores (Sunarto et al., 2013). Within the Bornean carnivore
60 guild is the Sunda stink-badger *Mydaus javanensis* (Leschenault, in Desmarest) (Fig. A1, Fig. A3);
61 a small, robust-bodied carnivore found across the Southeast Asian islands of Java, Sumatra,
62 Borneo, and the Natuna Archipelago. The species is amongst the least-studied within the Bornean
63 carnivore guild, yet is well known throughout the region for its “abominable odour” (Brehm, 1896).
64 Whilst the species is not considered under immediate threat, it is this lack of studies which makes
65 the Sunda stink-badger suitable for single-species targeted research.

66 The Sunda stink-badger is a nocturnal ground-dwelling skunk (Mephitidae) weighing 1.4–3.6 kg,
67 with a head-body length of 375–510 mm (Hwang & Lariviere, 2003). As is the case with nearly all
68 other carnivores in the region, there is a paucity of ecological data for the Sunda stink-badger.
69 Comments on its habitat use have varied significantly, with some sources suggesting it is mainly
70 found at high altitudes (Hwang & Lariviere, 2003); however, in some of its range the species has
71 shown extensive use of lowland plains (e.g. Sabah; Payne et al., 1985; Samejima et al., 2016). Little
72 is known of the threats facing the Sunda stink-badger, and it is currently listed as Least Concern by
73 the IUCN Red List of Threatened Species (Wilting et al., 2015). This listing is based on the
74 apparent ability of Sunda stink-badgers to withstand habitat degradation and fragmentation, paired
75 with the lack of records in large-scale bushmeat hunting reports, in the context of its large (relative
76 to Red List thresholds) geographical range and inferred large population (Samejima et al., 2016).

77 There are indications of a historical reduction in the distribution of the Sunda stink-badger in parts
78 of Borneo; however, these suspected declines are poorly understood and there is only speculation as
79 to the causes (Samejima et al., 2016).

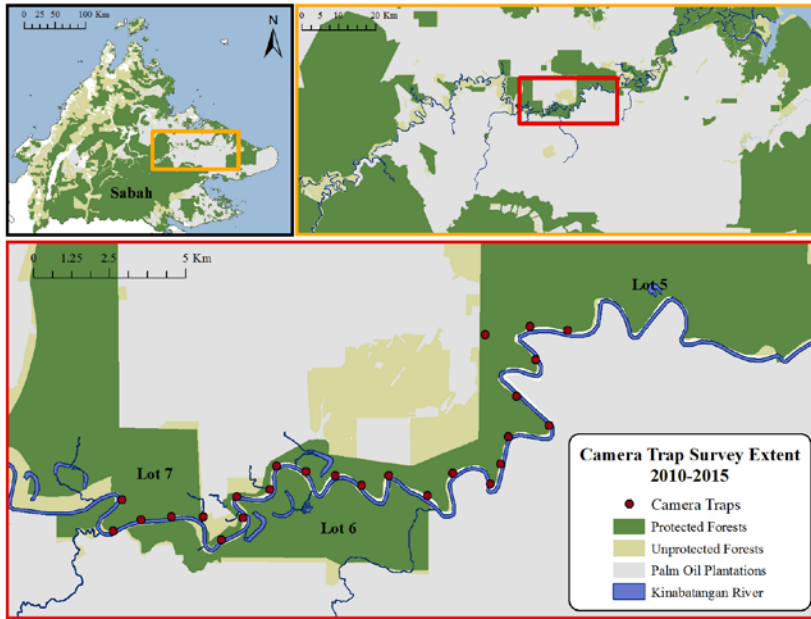
80 An aspect largely unstudied in the Sunda stink-badger is its circadian activity pattern. This is the 24
81 h cyclical pattern describing when a species is active (i.e. not resting), something that is often
82 variable between species, seasons of the year, and habitats. Historically, the frequency or proportion
83 of species' detection records within sections of the diel have been widely used to report activity
84 patterns (e.g.: Azlan & Lading, 2006); however, this outdated approach has been replaced by more
85 accurate statistical modelling methodologies such as kernel density estimators (Ridout & Linkie,
86 2009; Linkie & Ridout, 2011). Currently, broadly nocturnal activity is universally reported for the
87 Sunda stink-badger (Samejima et al., 2016); however, no more precise pattern has been
88 documented. Understanding the daily cyclical patterns of species activity is intrinsically valuable
89 for furthering our understanding of a species and its niche, but it can also be utilised as an indicator
90 of species' responses to ecological change. Analysis of long-term camera trapping data from the
91 Lower Kinabatangan Wildlife Sanctuary was undertaken to develop the first detailed circadian
92 activity pattern for the Sunda stink-badger. Activity here refers to movement along and around
93 wildlife trails, as detectable by the study design. Any behaviours that may not occur on trails would
94 thus not be detected. These baseline data will contribute to a greater understanding of this poorly
95 known species in the lowland plains of Malaysian Borneo.

96 MATERIALS AND METHODS

97 **Study area.** The Lower Kinabatangan Wildlife Sanctuary (LKWS, 279.6 km², elevation 10–200 m)
98 is situated in the Lower Kinabatangan floodplain of Eastern Sabah, Malaysian Borneo (5°10'–
99 5°50'N, 117°40'–118°30'E). Running through the sanctuary is the 560 km long Kinabatangan River,
100 which has an extensive floodplain with limestone ridge formations. The sanctuary consists of 10
101 protected lots with varying degrees of disturbance history and isolation from extensive native forest.

102 Lots are comprised of a mixture of semi-inundated, humid forest systems, along with regions of
103 permanent swamp, grasslands, and eventually mangroves at the coast. The area is recovering from
104 selective logging that occurred repeatedly over the past century (Brookfield & Byron, 1990) and is
105 surrounded by large areas of agricultural oil palm (*Elaeis guineensis*) plantations. Temperature
106 fluctuations are low with a mean monthly temperature range of 21°–34° Celsius, and annual rainfall
107 averages 3,000 mm (Ancrenaz et al., 2004).

108 **Camera trapping.** Biodiversity monitoring of the wildlife sanctuary was undertaken using camera
109 traps from 12 November 2010 until 09 May 2015, and camera trap placements were designed to
110 optimise the probability of recording Sunda clouded leopards *Neofelis diardi*. Cameras were active
111 throughout the study period with the exception of a 7-month break in camera trapping between
112 March and November of 2011. A total of 25 camera stations were utilised during the study effort;
113 however, active stations varied in number. Each station consisted of two Reconyx HyperFire
114 Professional Infrared (IR) passive camera traps (Model HC500 or PC800, Reconyx, Holmen, USA)
115 placed in armour casing to protect from damage and theft. Cameras were set ~0.5 m above ground
116 level on trees facing each other but were placed slightly off-set to avoid camera flash obstructing
117 the opposing unit. Cameras were active throughout the diel, and when movement across the IR
118 detection beam of an object with a different surface temperature from background objects
119 occurred, a series of three photos at 1-second intervals were taken. At low light conditions, an IR
120 flash illuminated the subject, as this allows for successful imaging of an animal subject with lower
121 disturbance than with white light (Ancrenaz et al., 2012). Stations were selected on existing riverine
122 wildlife trails and were cleared of ground foliage to improve picture quality and reduce false camera
123 triggers. Stations were not baited during the study effort. Camera traps were situated within a strip
124 of LKWS forest along the northern bank of the Kinabatangan River, which acts as a wildlife
125 corridor between two larger forest blocks. This corridor is part of Lot 5 of the LKWS and is flanked
126 by the Kinabatangan River and a large oil palm plantation (Fig. 1). Camera trap stations were
127 spaced at least 1 km apart in order to minimize spatial autocorrelation.



128

129 Fig. 1. Location of the camera trap stations in Lots 5 and 7 of the LKWS along the northern bank of the Kinabatangan River, Sabah,
 130 Malaysian Borneo.

131 **Data entry and analysis.** Prior to analysis, metadata were extracted from the images, including
 132 time, date, moon phase, image number, and a range of image quality specifics. Metadata extraction
 133 was completed using ExifTool 9.6.8.0. Images were individually examined and the species
 134 identified and logged. Each burst of three images was considered a single photo-capture. In order to
 135 reduce pseudoreplication, photo-captures were classed as unique and separate photographic events
 136 when an interval of >30 minutes between photo-captures of the same species were recorded, per
 137 Yasuda & Tsuyuki (2012). Sunda stink-badger encounter rate was defined as the number of unique
 138 Sunda stink-badger photographic events recorded per 100 potential trap nights. Events were
 139 compiled and the timestamps of the first photo in each unique event were used to model the activity
 140 pattern. Group size was not taken into consideration for these analyses, such that photo-captures
 141 containing multiple individuals were considered a single event. Day-night cycles remain nearly
 142 constant throughout the year in the study area, with sunrise and sunset occurring at approximately
 143 0600 h and 1800 h local time (GMT +8), respectively. In this study, nocturnal activity was defined
 144 as photographic events between 1900–0459 h, diurnal as 0700–1659 h, and crepuscular as the

145 periods of 0500–0659 h and 1700–1859 h, following the design set by other researchers within the
146 region (Ross et al., 2013).

147 Sunda stink-badger activity pattern was modelled using kernel density estimators following the
148 methodology of Ridout & Linkie (2009) and the package ‘overlap’ (Meredith & Ridout, 2014);
149 with a bandwidth adjust value of 2 as per recommendations from Rowcliffe et al. (2014). To
150 evaluate the effects of season and lunar phase on badger behaviour, activity patterns were generated
151 for subsets of the data and an overlap analysis conducted between the two activity patterns.
152 Analysis of overlap in activity patterns was completed utilising the Ridout & Linkie (2009)
153 methodology and the package ‘overlap’ (Meredith & Ridout, 2014), with Dhat 4 estimator of
154 overlap, 10,000 bootstrap replicates, and the basic0 output for bootstrap confidence intervals. The
155 package ‘activity’ (Rowcliffe, 2015) was then used with 10,000 bootstrap replicates to statistically
156 test the probability that the two sets of observations came from the same distribution. Analysis of
157 overlap in activity patterns was completed between three pairings; the dry season (March–October)
158 compared to the wet season (November–February), full moon nights compared to new moon nights
159 (including two nights before and after the full and new moon nights), and ‘bright’ nights (full moon,
160 waxing gibbous, and waning gibbous) compared to ‘dim’ nights (new moon, new crescent, and old
161 crescent). Statistical analyses were conducted using the statistical software R (version 3.2.1, R
162 Development Core Team, 2015).

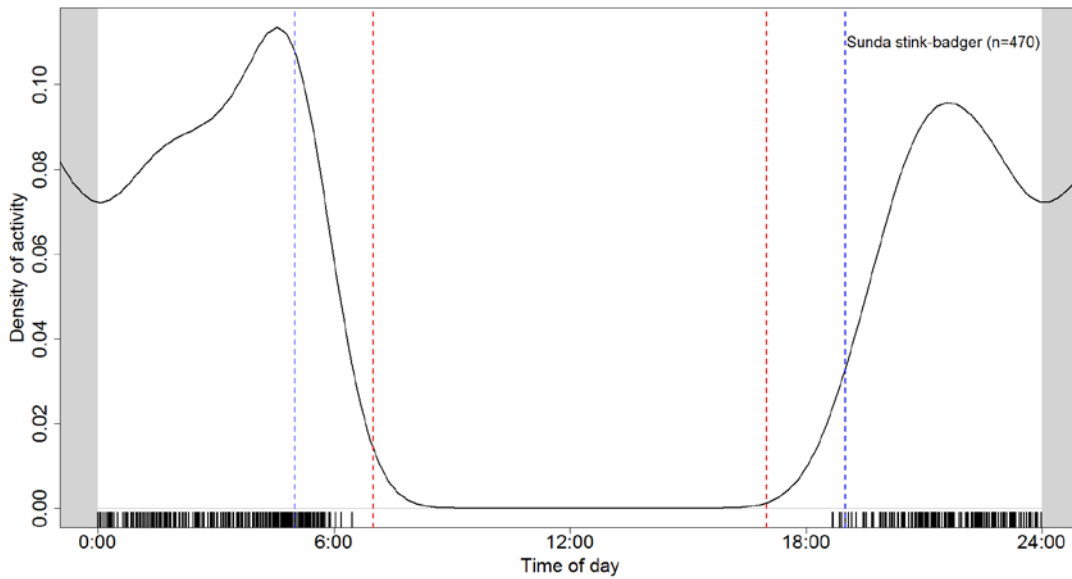
163

RESULTS

164 **Camera trapping overview.** The camera trapping effort ran for 48 non-consecutive months and
165 resulted in 24,506 total potential trap nights (sum of active calendar nights x number of active
166 camera traps). Potential trap nights have been used as a metric of data collection effort as the
167 precise timing of any camera malfunctions or battery death were not possible to ascertain. A total of
168 2,268 raw *M. javanensis* images (756 photo-captures) across 470 unique events were collected from
169 18 of the 25 camera stations. Single Sunda stink-badgers were recorded in the majority of events

170 (98.7%), with groupings of two individuals imaged in six unique events and never larger groupings
171 (Fig. A1), supporting the notion that the Sunda stink-badger is a solitary species (Samejima et al.,
172 2016). In all six events in which a duo was imaged, individuals were travelling the same direction
173 and route through the imaged area, were of similar size, and were assumed to be adults. All co-
174 occurrence events took place between the months of March–July; however, there was no distinctive
175 pattern in timing of these events in the diel. Whilst this could be an early indication of seasonal
176 mating or courtship, visual sexing was not possible, and as such, this assumption cannot be made.
177 Overall, the camera trapping effort returned 1.92 unique Sunda stink-badger events every 100
178 potential trap nights.

179 **Camera trap activity patterns.** The activity pattern of the Sunda stink-badger was modelled using
180 470 photographic events (Fig. 2). Within the LKWS, the Sunda stink-badger displayed a highly
181 nocturnal activity pattern, with no photographic events recorded within diurnal hours. The earliest
182 time in the evening a stink-badger was recorded was 1839 h, and the latest morning detection was
183 0627 h. Activity began and rose sharply within the crepuscular time period of 1700–1859 h and
184 then continued throughout nocturnal hours. Once the morning crepuscular hours (0500–0659 h)
185 began, stink-badger activity quickly fell. Sunda stink-badgers demonstrated two clear peaks in
186 activity, the first occurred around 2100 h, and the second around 0500 h with a greater magnitude.



187

188 Fig. 2. Daily activity patterns of Sunda stink-badger within Lot 5 of the Lower Kinabatangan Wildlife Sanctuary, Sabah, Malaysian
 189 Borneo. The grey areas represent an extension of the activity pattern to depict its circular nature, and ‘carpet’ marks along the x-axis
 190 represent individual photographic events. Vertical dashed red lines indicate either the end or beginning of the diurnal phase of the
 191 diel (0700–1659h). Vertical blue lines indicate either the end or beginning of the nocturnal phase of the diel (1900–0459h). Regions
 192 between red and blue lines represent the crepuscular regions of the diel (0500–0659h and 1700–1859h).

193 **Seasonal and lunar effects.** All tested overlaps of modelled activity patterns using subsets of
 194 Sunda stink-badger events were found to have high coefficients of overlap (≥ 0.8) (Table 1; Fig.
 195 A2). Statistical analysis found that none of the analysed overlaps were significantly different (Table
 196 1), indicating that the activity pattern of the Sunda stink-badger does not significantly vary between
 197 seasons or moon phase.

198 Table 1. Overlap coefficients for Sunda stink badger activity patterns across seasonal and lunar variation.

Activity pattern 1	Sample size (N) unique Sunda stink-badger events	Activity Pattern 2	Sample size (N) unique Sunda stink-badger events	Coefficient of overlap (Confidence interval)	P-value
Dry season (March-October)	339	Wet season (November-February).	131	0.90 (0.89-0.96)	0.69
Full moon	58	New moon	64	0.81 (0.71-0.93)	0.26
‘Bright’ nights (full moon, waxing gibbous, and waning gibbous)	165	‘Dim’ nights (new moon, new crescent, and old crescent).	183	0.90 (0.88-0.97)	0.72

199

200

DISCUSSION

201 These results provide the first detailed 24 h daily activity pattern for the Sunda stink-badger, a
202 metric currently only available for few of the Bornean carnivores, e.g. Sunda clouded leopard
203 *Neofelis diardi* (Cuvier) (Ross et al., 2013) and sun bear *Helarctos Malayanus* (Raffles) (Wong et
204 al., 2004). The Sunda stink-badger was found to be highly nocturnal, with activity primarily
205 between the hours of 1800 h and 0600 h. Furthermore, activity was not uniform throughout this
206 period and displayed two peaks at 2100 h and 0500 h. Whilst nocturnal activity between the hours
207 of 1800 h and 0600 h has been previously reported (Samejima et al., 2016), this is the first study to
208 show the intricacies of activity between these hours for this species. Over the five-year study
209 period, the study collected 470 photographic events of the Sunda stink-badger, the largest reported
210 collection of photographic events for this species in the wild at the time of publication. This
211 extensive data set has enabled a high level of accuracy within the kernel density modelled activity
212 pattern, avoiding accuracy issues associated with small sample sizes and seasonal biases that may
213 occur with shorter camera trapping studies (Oliveira-Santos et al., 2008; Chen et al., 2009; Cheyne
214 et al., 2010).

215 It is, however, important to note the potential bias within this study based on the trail-based
216 positioning of camera stations. The Sunda stink-badger's activity pattern presented here should
217 therefore be interpreted as its activity along wildlife trails. As an example, the lack of a single
218 image containing visibly young stink-badgers within such an extensive dataset supports the belief
219 that Sunda stink-badgers raise their young in secluded dens (Long & Killingley, 1983), a behaviour
220 unlikely to be detected with trail-based camera traps. Furthermore, the paucity of apparent mating
221 images similarly suggests this species may conduct reproductive courtship behaviours away from
222 wildlife trails, and future targeted studies should seek to place camera traps throughout a variety of
223 forest microhabitats. The deployment of technologies alternative to camera traps, such as radio
224 telemetry, satellite tracking, or collar-based accelerometers could provide researchers with even
225 more accurate insights into stink-badger activity patterns, especially for more fine-scale behaviours,

226 those involving little movement through the habitat, or those occurring off-trail (Shepard et al.,
227 2008; Nathan et al., 2012); however, these techniques do suffer from practical limitations of high
228 costs and limited sample sizes compared with camera trapping efforts. The most informative picture
229 of Sunda stink-badger ecology is therefore most likely to be generated from a mixture of research
230 methodologies deployed simultaneously, when financially viable. Despite the limitations of camera
231 trapping when deployed alone, the results of the activity pattern modelling have enhanced
232 understanding of the behavioural ecology of the Sunda stink-badger, and will act as baseline for
233 future ecological studies aiming to assess the species' activity pattern.

234 The analysis of a species' activity pattern can indicate how a species responds to environmental and
235 biological pressures. Seasonal variations in activity patterns have been recorded for many species
236 (Patterson et al., 1999; Donadio et al., 2006); however, no such variation was found for the Sunda
237 stink-badger in this study. Additionally, many nocturnal species also vary their activity across the
238 lunar cycle (Di Bitetti et al., 2006; Donadio et al., 2006), yet no such behaviour was documented for
239 the Sunda stink-badger. Activity patterns may also vary due to inter- and intra-specific competition,
240 which often results in temporal niche partitioning (Lucherini et al., 2009), or predator-prey
241 interactions, whereby species can shift activity patterns to either increase hunting success as
242 predators or maximise survival as prey (Ross et al., 2013). Predation pressures on the Sunda stink-
243 badger are expected to be limited due to the stink-badger's anal scent-gland secretions acting as a
244 powerful deterrent to any potential predators. Although there are unsubstantiated reports of civets
245 preying upon Sunda stink-badgers from popular science websites (Krauskopf, 2002), in four of our
246 470 photographic events (0.85%), a Sunda stink-badger was photographed co-occurring with a
247 Malay civet (*Viverra zibetha*). In all co-occurrence events, there were no observed indications
248 of physical contact or any behavioural interactions between the two species (Fig. A3). All instances
249 of co-occurrence took place within areas with no obviously discernable presence of a concentrator
250 of activity (e.g salt lick), and are instances of photographic events where both species were imaged

251 simultaneously in the same frame. This represents one of very few documented cases of Sunda
252 stink-badger in close proximity to another species of carnivore.

253 Activity is, however, also heavily influenced by dietary demands in carnivores (Ross et al., 2013).
254 Understanding of Sunda stink-badger diet is limited, although an omnivorous diet is reported
255 (Payne et al., 1985) and the stomach contents of a dissected individual indicated a diet abundant in
256 large earthworm species (Davis, 1961). Nocturnality in predators of earthworms is common, and is
257 believed to be a result of nocturnal vertical migration to the soil surface by some earthworm species
258 (Duriez et al., 2006). This may help explain the nocturnal activity pattern found in the Sunda stink-
259 badger, perhaps even the two peaks in activity, as some earthworm species surface in the early
260 evening and early morning (Lee, 1985).

261 Whilst dietary pressures are suspected to be the predominant generator of the broad activity pattern
262 for Sunda stink-badgers in the LKWS, pressures may also be anthropogenic in nature. For example,
263 the activity pattern of a species can vary in response to pressures such as hunting, habitat
264 destruction, and other anthropogenic activities (Frederick, 2008; Presley et al., 2009; Marchand et
265 al., 2014; Poudel et al., 2015). Close proximity to oil palm plantations, local road infrastructure, and
266 the Kinabatangan River increases human accessibility into the LKWS, bringing tourism, fishermen,
267 and illegal hunters, all of which heighten anthropogenic disturbances within the sanctuary. This
268 anthropogenic disturbance is also exacerbated by the considerable historical habitat degradation that
269 has occurred in the area through repeated selective logging during the 20th century. As such, the
270 stink-badger's activity pattern presented here could be reflective of the highly disturbed
271 environment within the LKWS.

272 Despite many records of Sunda stink-badger being available (Samejima et al., 2016), very few
273 studies have obtained sizeable encounter datasets within a single area as presented here
274 (Matsubayashi et al., 2007; Wilting et al., 2010; Bernard et al., 2013). Of those studies with many
275 Sunda stink-badger records, all have occurred within the Malaysian state of Sabah; however, even

276 within this limited scope, discernible differences in site ecology and disturbance regimes can allow
277 for preliminary comparisons between studies. Within our LKWS camera trapping effort, 1.92
278 unique Sunda stink-badger events were recorded every 100 trap nights and the species was the
279 second most commonly imaged carnivore in the survey (Evans et al., 2016). This encounter rate can
280 be compared with other studies in an attempt to analyse the effect of site differences on local
281 abundance. Whilst encounter rates (often naively but inappropriately termed Relative Abundance
282 Indices) are increasingly considered a dated methodology for assessing abundances, particularly
283 between species (Sollmann et al., 2013), with so few studies assessing Sunda stink-badger
284 photographic rates (Matsubayashi et al., 2007; Wilting et al., 2010; Bernard et al., 2013), an
285 encounter rate provides a comparative preliminary indicator of status for this under-studied species.
286 Only three other studies have produced this measure or provided sufficient information for an
287 encounter rate to be calculated for the Sunda stink-badger (Table A1), two of which were
288 undertaken within the Deramakot Forest Reserve (DFR) situated further upstream on the
289 Kinabatangan River. The third study was undertaken within Tabin Wildlife Reserve, Sabah;
290 however, due to very low sample size, the results are not suitable for comparison here (Bernard et
291 al., 2013). The two studies at DFR recorded 3.66 (Matsubayashi et al., 2007) and 3.60 (Wilting et
292 al., 2010) unique Sunda stink-badger photographic events per 100 trap nights, which may be an
293 indication that the species is comparatively less common in the LKWS than in DFR (Table A1).
294 Given the higher amounts of habitat degradation and anthropogenic disturbance within the LKWS
295 area compared to DFR (the LKWS is smaller, more fragmented, and more isolated from other
296 native forest); these results may suggest that the Sunda stink-badger is more susceptible to
297 anthropogenic disturbance than previously thought. However, caution must be advised with this
298 interpretation due to differences in study methodologies and relatively small sample sizes; for
299 example, whilst cameras were set on wildlife trails in both of the compared studies, localised
300 features such as rivers and salt licks varied. This variation in relative encounter rate between study

301 areas does, however, emphasise the importance of understanding how the behavioural ecology of
302 this species may also vary across study sites.

303 Sunda stink-badgers have been observed in a wide variety of habitats including lowland forest,
304 montane forests, forest mosaic, and non-forest at both protected and unprotected sites. Whilst
305 presence may indicate human-modified habitats in the LKWS are used by the species, it does not
306 necessarily indicate optimal habitat and gaining a greater understanding of Sunda stink-badger
307 species' ecology remains pertinent. Particularly given the suggestion, above, that encounter rates
308 (and thus perhaps population densities) might be lower in more degraded and fragmented habitats,
309 further studies of Sunda stink-badger behaviour are warranted to investigate to what extent habitat
310 quality and human disturbance may be impacting the species. Whilst the persistence of Sunda stink-
311 badger is not considered to be in immediate danger, improving knowledge of the species' ecology is
312 nevertheless useful. Furthermore, the methodology utilised here is easily adopted and, due to the
313 vast volume of camera trapping taking place within the region, can be applied to a plethora of other
314 under-studied ground-dwelling species.

315 **ACKNOWLEDGEMENTS**

316 We thank the Sabah Wildlife Department and the Sabah Biodiversity Centre for issuing the research
317 permits necessary to conduct this study. We also thank Houston Zoo, Sime Darby Foundation and
318 Danau Girang Field Centre for their generous funding which made this research possible. Data
319 collection for this research project was greatly aided by the input of Danica J. Stark, and the
320 research assistants at Danau Girang Field Centre. A significant amount of effort was also
321 contributed by the following Cardiff University Professional Training Year students: Rob Colgan,
322 Rodi Tenquist-Clarke, Josie D'Urban Jackson, Alice Miles, Becky Lawrence, Michael Reynolds,
323 Isaac Fields, Helen Cadwallader, Grace Dibden, Hannah Wilson, Kieran Love, Anya Tober, Sarah
324 Joscelyne, Kirsty Franklin, Roxanne Everitt, Aimee Holborow, and Rhys White. Finally, we also

325 thank the anonymous reviewers for their valuable comments which served to improve the resultant
326 manuscript greatly.

327 **LITERATURE CITED**

328 Ancrenaz M, Goossens B, Gimenez O, Sawang A & Lackman-Ancrenaz I (2004) Determination of
329 Ape Distribution and Population Size Using Ground and Aerial Surveys : A Case Study with
330 Orang-Utans in lower Kinabatangan, Sabah, Malaysia. *Animal Conservation*, 7: 375–385.

331 Ancrenaz M, Hearn AJ, Ross J, Sollmann R & Wilting A (2012) Handbook for wildlife monitoring
332 using camera traps. BBEC II Secretariat. Kota Kinabalu, Sabah, Malaysia.

333 Bernard H, Baking EL, Giordana AJ, Wearn OR & Ahmad AH (2014) Terrestrial mammal species
334 richness and composition in three small forest patches within an oil palm landscape in Sabah,
335 Malaysian Borneo. *Mammal Study*, 39(3): 141–154.

336 Brehm AE (1896) *Brehm's Life of Animals*. A. N. Marquis & Company, Chicago, USA, 173 pp.

337 Brookfield H & Byron Y (1990) Deforestation and timber extraction in Borneo and the Malay
338 Peninsula: The record since 1965. *Global Environmental Change*, 1(1): 42–56.

339 Chen MT, Tewes ME, Pei KJ & Grassman LI (2009) Activity Patterns and Habitat Use of
340 Sympatric Small Carnivores in Southern Taiwan. *Mammalia*, 73: 20–26.

341 Cheyne SM, Husson SJ, Chadwick RJ & Macdonald DW (2010) Diversity and Activity of Small
342 Carnivores of the Sabangau Peat-Swamp Forest, Indonesian Borneo. *Small Carnivore
343 Conservation*, 43: 1–7.

344 Cuellar E, Maffei L, Arispe R & Noss A (2006) Geoffroy's Cats at the Northern Limit of Their
345 Range: Activity Patterns and Density Estimates from Camera Trapping in Bolivian Dry
346 Forests. *Studies on Neotropical Fauna and Environment*, 41: 169–177.

- 347 Davis DD (1961) Mammals of the lowland rainforest of North Borneo. Bulletin of the National
348 Museum, 31:1–129.
- 349 Di Bitetti MS, Paviolo A & De Angelo C (2006) Density, habitat use and activity patterns of
350 ocelots (*Leopardus pardalis*) in the Atlantic Forest of Misiones, Argentina. Journal of Zoology
351 (London), 270: 153–163.
- 352 Donadio, Kauhala K, Holmala K & Schregel J (2006) Seasonal activity patterns and movements of
353 the raccoon dog, a vector of diseases and parasites, in southern Finland. Mammalian Biology,
354 72: 342–353.
- 355 Duriez O, Ferrand Y & Binet F (2006) An Adapted Method for Sampling Earthworms at Night in
356 Wildlife Studies. Journal of Wildlife Management, 70(3): 852–858.
- 357 Evans MN, Vickers SH, Abu-Bakar MS & Goossens B (2016) Small Carnivores of the Lower
358 Kinabatangan Wildlife Sanctuary, Sabah, Borneo, including a new locality for the Otter Civet
359 *Cynogale bennettii*. Small Carnivore Conservation, 54: 26–38.
- 360 Frederick CA (2008) The Reproductive Biology and Behaviour of the sun bear *Ursus malayanus*.
361 University of Washington, UMI.
- 362 Hwang YT & Lariviere S (2003) *Mydaus javanensis*. American Society of Mammologists 723: 1–3.
- 363 IUCN (2016) The IUCN Red List of Threatened Species. *Version 2016-2*.
364 <http://www.iucnredlist.org> (Accessed 07 November 2016).
- 365 Krauskopf R (2002) "*Mydaus javanensis*". Animal Diversity Web.
366 http://animaldiversity.org/accounts/Mydaus_javanensis/ (Accessed 21 November 2016).
- 367 Lee KE (1985) Earthworms. Their ecology and relationships with soils and land use Academic,
368 Sydney, Australia.

- 369 Linkie M & Ridout MS (2011) Assessing tiger-prey interactions in Sumatran rainforests. *Journal of*
370 *Zoology*, 284: 224-229.
- 371 Long CA & Killingley CA (1983) *The Badgers of the World*. Charles C. Thomas, Springfield,
372 Illinois.
- 373 Lucherini M, Reppucci JI, Walker RS, Villalba ML, Wurstten A, Gallardo G, Iriarte A, Villalobos
374 R & Perovic P (2009) Activity pattern segregation of carnivores in the high Andes. *Journal of*
375 *Mammalogy*. 90(6): 1404–1409.
- 376 Marchand P, Garel M, Bourgoïn G, Dubray D, Maillard D & Loison A (2014) Impacts of tourism
377 and hunting on a large herbivore's spatio-temporal behavior in and around a French protected
378 area. *Biological Conservation*, 177: 1–11.
- 379 Matsubayashi H, Lagan P, Majalap N, Tangah J, Sukor JRA & Kitayama K (2007) Importance of
380 natural licks for the mammals in Bornean inland tropical rain forests. *Ecological Research*,
381 22(5): 742–748.
- 382 Meredith M & Ridout M (2014) *Overlap: Estimates of coefficient of overlapping for animal activity*
383 *patterns*. R package version 0.2.6. <http://CRAN.R-project.org/package=overlap> (Accessed 08
384 November 2016).
- 385 Nathan R, Spiegel O, Fortmann-Roe S, Harel R, Wikelski M & Getz WM (2012) Using tri-axial
386 acceleration data to identify behavioral modes of free-ranging animals: general concepts and
387 tools illustrated for griffon vultures. *Journal of Experimental Biology*, 215(6): 986–996.
- 388 Oliveira-Santos LGR, Tortato MA & Graipel ME (2008) Activity Pattern of Atlantic Forest Small
389 Arboreal Mammals as Revealed by Camera Traps. *Journal of Tropical Ecology*, 24: 563–567.

- 390 Patterson BR, Bondrup-Nielsen S & Messier F (1999) Activity patterns and daily movements of the
391 eastern coyote, *Canis latrans*, in Nova Scotia. *Canadian Field Naturalist*, 113: 251–257.
- 392 Payne J, Francis CM & Phillipps K (1985) *A Field Guide to the Mammals of Borneo*. The Sabah
393 Society, Kota Kinabalu, Malaysia.
- 394 Poudel BS, Spooner PG & Matthews A (2015) Temporal shift in activity patterns of Himalayan
395 marmots in relation to pastoralism. *Behavioural Ecology*, 26(5): 1345–1351.
- 396 Presley SJ, Willig MR, Catro-Arellano I & Weaver SC (2009) Effects of habitat conversion on
397 temporal activity patterns of Phyllostomid bats in lowland Amazonian rain forest. *Journal of*
398 *Mammalogy*, 90(1): 210–221.
- 399 R Core Team (2015) *R: A language and environment for statistical computing*. Foundation for
400 *Statistical Computing*, Vienna, Austria. <http://www.R-project.org/> (10 August 2015).
- 401 Ridout MS & Linkie M (2009) Estimating overlap of daily activity patterns from camera trap data.
402 *Journal of Agricultural, Biological, and Environmental Statistics*, 14(3): 322–337.
- 403 Ross J, Hearn AJ, Johnson PJ & Macdonald DW (2013) Activity Patterns and Temporal Avoidance
404 by Prey in Response to Sunda Clouded Leopard Predation Risk. *Journal of Zoology*, 290(2):
405 96–106.
- 406 Rowcliffe M (2015) Package ‘activity’: animal activity statistics. Version 1.1. [http://CRAN.R-](http://CRAN.R-project/package=activity)
407 [project/package=activity](http://CRAN.R-project/package=activity). (Accessed 16 June 2017).
- 408 Samejima H, Meijaard E, Duckworth JW, Yasuma S, Hearn AJ, Ross J, Mohamed A, Alfred R,
409 Bernard H, Boonratana R, Pilgrim JD, Eaton J, Belant JL, Kramer-Schadt S, Semiadi G &
410 Wilting A (2016) Predicted distribution of the Sunda stink-badger *Mydaus javanensis*
411 (Mammalia: Carnivora: Mephitidae) on Borneo. *Raffles Bulletin of Zoology*, 33: 61–70.

412 Shepard EL, Wilson RP, Quintana F, Laic AG, Liebsch N, Albareda DA, Halsey LG, Gleiss A,
413 Morgan DT, Myers AE, Newman C & Macdonald DW (2008) Identification of animal
414 movement patterns using tri-axial accelerometry. *Endangered Species Research*, 10: 46–60.

415 Shepherd CR, Belant JL, Breitenmoser-Würsten C, Duplaix N, Ambu LN & Wilting A (2011)
416 Conservation challenges and opportunities for Borneo’s carnivores. *TRAFFIC Bulletin*, 23:
417 89–91.

418 Silveira L, Jácomoa ATA & Diniz-Filho JAF (2003). Camera Trap, Line Transect Census and
419 Track Surveys : A Comparative Evaluation. *Biological Conservation*, 114(3): 351–355.

420 Sollmann R, Mohamed A, Samejima H & Wilting A (2013) Risky business or simple solution –
421 Relative abundance indices from camera-trapping. *Biological Conservation*, 159: 405–412.

422 Sunarto, Sollmann R, Mohamed A & Kelly MJ (2013) Camera trapping for the study and
423 conservation of tropical carnivores. *The Raffles Bulletin of Zoology*, 28: 21–42.

424 Wilting A, Samejima H & Mohamed A (2010) Diversity of Bornean viverrids and other small
425 carnivores in Deramakot Forest Reserve, Sabah, Malaysia. *Small Carnivore Conservation*, 42:
426 10–13.

427 Wilting A, Duckworth JW, Meijaard E, Ross J, Hearn A & Ario A (2015) *Mydaus javanensis*. The
428 IUCN Red List of Threatened Species 2015. [http://dx.doi.org/10.2305/IUCN.UK.2015-](http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T41628A45209955.en)
429 [4.RLTS.T41628A45209955.en](http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T41628A45209955.en). (Accessed 22 June 2017).

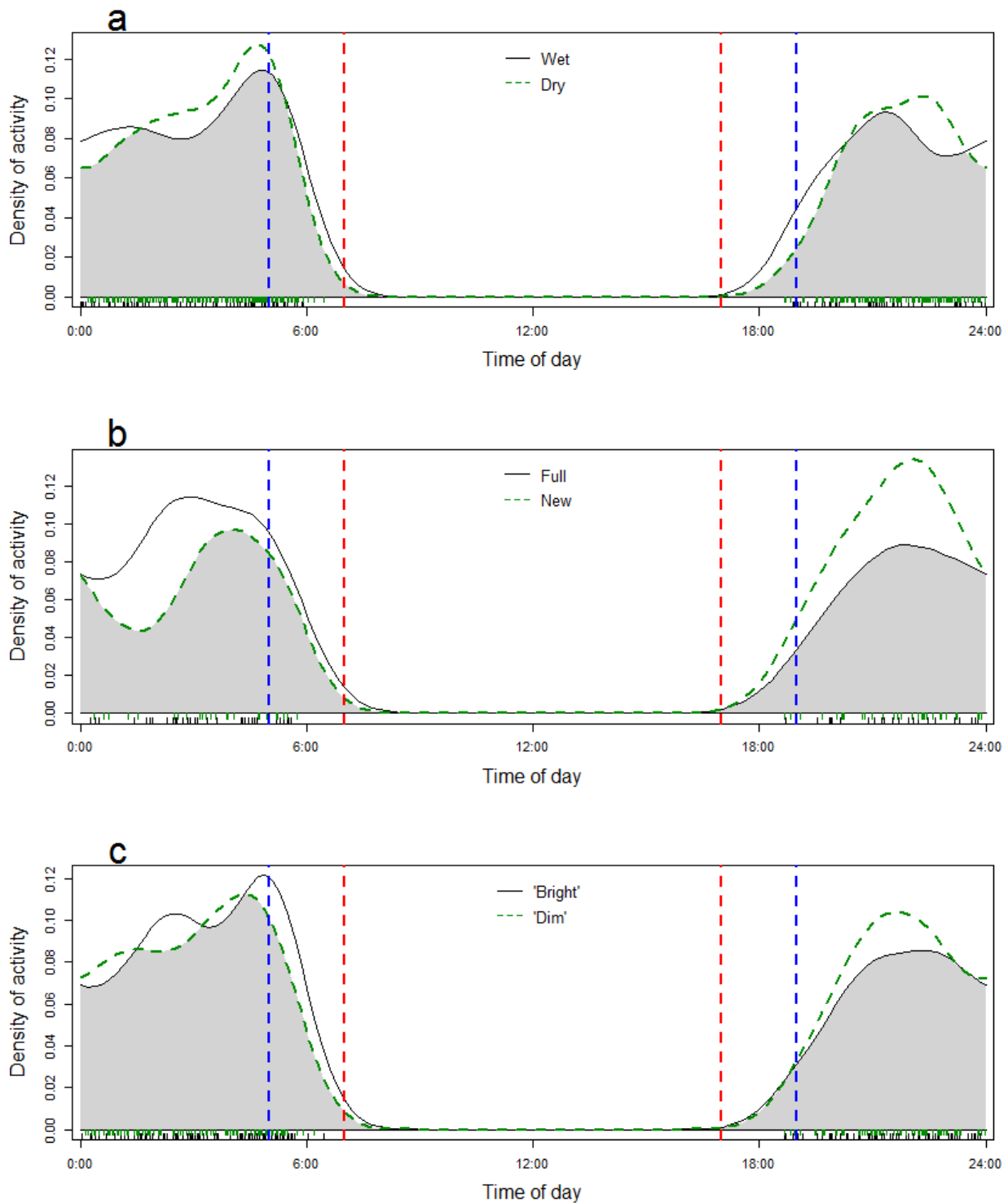
430 Wong ST, Servheen C & Ambu L (2004) Home range, movement and activity patterns, and
431 bedding sites of Malayan Sun Bears *Helarctos malayanus* in the Rainforest of
432 Borneo. *Biological Conservation*, 119: 169–181.

433 Yasuda RM & Tsuyuki S (2012) Comparison of mammalian communities in a human-disturbed
434 tropical landscape in East Kalimantan, Indonesia. *Mammal Study*, 37(4): 299–311.
435



437

438 Fig. A1. A pair of Sunda stink-badgers *Mydaus javanensis* photo-captured in the Lower Kinabatangan Wildlife Sanctuary, Sabah,
439 Malaysian Borneo on 09 March 2009.



440

441 Fig. A2. Kernel density modelled activity patterns for the Sunda stink-badger during different periods; overlap between activity
 442 patterns is indicated by the shaded regions. Vertical dashed red lines indicate either the end or beginning of the diurnal phase of the
 443 diel (0700–1659h). Vertical blue lines indicate either the end or beginning of the nocturnal phase of the diel (1900–0459h). Regions
 444 between red and blue lines represent the crepuscular regions of the diel (0500–0659h and 1700–1859h). ‘Carpet’ marks along the x-
 445 axis represent individual photographic events, and are colour co-ordinated to their respective activity pattern. Top (a): Overlap in
 446 kernel density modelled activity pattern in the wet season (November–February) compared to the dry season (March–October).

447 Middle (b): Overlap in kernel density modelled activity pattern on full moon nights compared to new moon nights. Bottom (c):
 448 Overlap in kernel density modelled activity pattern on 'bright' nights (full moon, waxing gibbous, and waning gibbous) compared to
 449 'dim' nights (new moon, new crescent, and old crescent).



450
 451 Fig. A3. Co-occurrence of Sunda stink-badger *Mydaus javanensis* and Malay civet *Viverra zibetha* photo-captured in the Lower
 452 Kinabatangan Wildlife Sanctuary, Sabah, Malaysian Borneo on 13 June 2013.

453 Table A1. Comparisons between remote camera trapping studies that have observed the Sunda stink-badger *Mydaus javanensis*.

Reference	Study site	Trap nights	Photographic Events	No. of unique photographic events per 100 potential trap nights	Notes	Study period
Matsubayashi et al., 2007	Deramakot Forest Reserve	981	36	3.66	Salt lick at 5 of 15 sites, area sustainably logged during study period.	June 2003 – October 2005
Wilting et al., 2010	Deramakot Forest Reserve	1,916	69	3.60	Camera traps placed within large contiguous forest patch.	July 2008 – January 2009
Bernard et al., 2013	Tabin Wildlife Reserve	307	2	0.65	Forest patch within oil palm plantation.	September 2009 – December 2009 and May 2010 – August 2010

Bernard et al., 2013	Tabin Wildlife Reserve	229	1	0.44	Forest patch within oil palm plantation.	September 2009 – December 2009 and May 2010 – August 2010
Current study	Lower Kinabatangan Wildlife Sanctuary	24,506	470	1.92	Highly fragmented riverine study site, with extensive areas of oil palm plantations.	November 2010 – May 2015

454

455 **Figure Captions:**

456 Fig. 1. Location of the camera trap stations in Lots 5 and 7 of the LKWS along the northern bank of the Kinabatangan River, Sabah,
 457 Borneo.

458 Fig. 2. Daily activity patterns of Sunda stink-badger within Lot 5 of the Lower Kinabatangan Wildlife Sanctuary, Sabah, Borneo. The
 459 grey areas represent an extension of the activity pattern to depict its circular nature, and ‘carpet’ marks along the x-axis represent
 460 individual photographic events. Vertical dashed red lines indicate either the end or beginning of the diurnal phase of the diel (0700–
 461 1659h). Vertical blue lines indicate either the end or beginning of the nocturnal phase of the diel (1900–0459h). Regions between red
 462 and blue lines represent the crepuscular regions of the diel (0500–0659h and 1700–1859h).

463 **Tables:**

464 Table 1. Overlap coefficients for Sunda stink badger activity patterns across seasonal and lunar variation.

Activity pattern 1	Sample size (N) of unique Sunda stink-badger events	Activity Pattern 2	Sample size (N) of unique Sunda stink-badger events	Coefficient of overlap (Confidence interval)	P-value
Dry season (March-October)	339	Wet season (November-February)	131	0.90 (0.89-0.96)	0.69
Full moon	58	New moon	64	0.81 (0.71-0.93)	0.26
‘Bright’ nights (full moon, waxing gibbous, and waning gibbous)	165	‘Dim’ nights (new moon, new crescent, and old crescent)	183	0.90 (0.88-0.97)	0.72

465